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El Campo Solar Radar Antenna Modification

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LINCOLN LABORATORY

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ABSTRACT

The east-west aperture of the El Campo Solar Radar Antenna was doubled. Mechanical and electrical improvements incorporated at the time of the expansion, together with the increased size, resulted in an increase in gain of approximately 3-1/4 db.

Accepted for the Air Force
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I. INTRODUCTION

An antenna was installed at the El Campo Texas Field Site early in 1961 for use in a solar radar system operating at 38.25 Mcps (Fig. 1). This antenna is an array of dipoles which are arranged in eight rows of 127 elements each. The inter- and intra-row spacing is the same, 13'9" or .5343 wavelengths (λ). The design of the antenna and the measurements made on the installed antenna have been described completely in TR-276.[1] This report is essentially an addendum to that report describing minor modifications and it will be assumed throughout that the reader is familiar with the former treatise.

After the system was in operation for a little over a year, it became apparent that an additional 3 db sensitivity in the transmitting system would greatly enhance the results of the solar experiments, although satisfactory results were obtained most of the time. It was necessary to achieve this increase entirely in the transmitting system (for solar experiments) since any refinement in the receive system only increases the received solar noise as well as the radar returns. This increased sensitivity could be accomplished in two ways: 1) in transmitter power, or 2) in antenna gain. The cost of increasing the gain of the antenna was a fraction (1/3 or 1/4) of the cost of the new transmitter and the associated transmission lines that would be required.

Since cost was the main factor in the decision, plans were made to increase the gain of the antenna. The beamwidths of the antenna are 3/4° in the north-south plane by 12° in the east-west plane. The measured gain is 33-1/4 db. The antenna beamwidth in the north-south plane is already as narrow as possible without encountering scintillation problems. For this reason it was decided to double the aperture in the east-west dimension (Fig. 1b) with the resultant halving of the beamwidth in that plane and an increase of approximately 3 db in antenna gain. This narrowing of the beamwidth in the east-west plane would necessitate the scanning of the receive beam, but this is a minor problem.

II. PHYSICAL DESCRIPTION OF THE EXPANSION

In keeping with the desire for a minimum cost expansion, any parts of the original array which could be reused were simply moved to another portion of the array. Each of the major portions of the array will be described in detail under its specific heading.

1. Element Spacing

There are two ways in which the elements could be installed to provide approximately the same gain over the entire range of north-south scan angles without radically changing the design. The entire area could be filled with elements as it was in the original array. That is, the elements would be spaced $.5343\lambda$ apart both north-south and east-west. In this case, each output of the trough line would be divided to feed two elements. The alterna-

tive to this is to install the dipoles in a triangular lattice as was done with the orthogonal array.[1] In this case, there would be half as many elements and feed cables and naturally the cost of the array would be less. The difference in coverage is illustrated in Fig. 2a and Fig. 2b. Figure 2a shows the solid angle over which the beam of the principal array may be scanned without the formation of grating lobes if the array has square spacing. Figure 2b shows the grating lobe structure of the triangular spaced array. For scan angles greater than 36° in the north-south plane there is a grating lobe formed, however, even at 60° it is still -13 db so less than 1/4 db is lost at the maximum scan angle of 52.5°. Off the principal axes, the scanning capability of the triangular lattice arrangement is quite restricted. When the array was originally conceived, it was necessary to build the antenna so that it could be scanned to any angle in a 60° cone. At that time there was a possibility that sometime in the future electronic scanning would be installed. This rapid scanning is needed to track celestial objects. Since then, however, it has become apparent that the several million dollars needed to install electronic scanning will never be available so the limitations imposed by the triangular lattice are now acceptable. For this reason, plus the cost factor, the triangular spacing was chosen. The cost of installing the triangular spacing was approximately $40,000 as opposed to an estimated $70,000 for the square array.

2. Trough Line

A large part of the cost of the original array was the trough transmission line[1] from which each of the dipoles was fed. There are eight of these lines each 1746 feet long. It was decided to use only the same eight lines, but to rearrange them and the 6-1/8-inch coaxial feed lines to feed the expanded array (Fig. 3). The trough lines were installed at a greater distance above the ground (the bottom two feet above the ground). This was done for two reasons:

(a) To avoid the difficulties with the grass growing in the lines.[1]

(b) To facilitate phasing and maintenance work.

3. Coupling Coefficients and Couplers

In order to feed the elements, some of the power in the main transmission line (trough line) which runs the length of the array, must be periodically removed from this main transmission line. A device called a coupler is inserted every 13 feet, 9 inches. The formulae and theory are given in TR-276,[1] pages 9 through 11. These formulae describe the means of calculation of the amount of coupling in order that the same amount of power appears at each output. Figure 4 shows the calculated values of coupling as a function of coupling number for a line loss of 1.2 db and a spacing between couplers of 192.367°. The values are quite different from the value of couplers installed in the original array. This is true for two reasons. The computer program to calculate the values was unavailable at that time and when the array was

first installed, the couplers were found to break down under high power. A modified design was installed without compensating for the change in value of coupling caused by the modification. Since each coupler was now being removed from the trough line, in order that the trough line could be raised, we took advantage of this opportunity to modify every coupler to conform to the calculated values as well as incorporating mechanical improvements. Figure 4 also shows the value of couplers installed. The two designs, shown in Fig. 5a and Fig. 5b were measured to determine their coupling value as the length was changed (Fig. 6). Figure 5a shows what might be called the high-power design; that is, it is the coupler design which has proved the most satisfactory from an electrical standpoint. This type was used in that part of each trough line nearest the transmitter as far as possible consistent with the coupling values available. The coupler shown in Fig. 5b was used and finally the type shown in Fig. 7. This type (Fig. 7) was the original design by Radiation Engineering Laboratory and their design curves were used in the choice of coupling value.

4. Power and Phase and Feeder Line Outputs

The power output of each of the couplers was measured when each output was terminated in a 50Ω load. The results obtained with a typical line are shown in Fig. 8 along with the calculated output. The results for 3/4 of the array represent a great improvement over the results of the previous array. The amplitude variation is approximately ± 0.8 db. At the point where the

original type couplers are inserted, element 92, there is a 2 db variation from the calculated coupling.

The effect of loading the lines with the couplers is to increase the phase of the output of the couplers as compared with that of an unloaded line. As shown in TR-276, this phase change must be compensated for or a reduction in gain of about 1.5 db occurs. Figure 9 shows the increase in the phase measured vs. the theoretical. The measured values are larger than the calculated. The same situation occurred in the previous set of measurements. This additional phase change has been attributed to the bullet-type connectors in the inner conductor and the reflection from the inner conductor supports. Both effects are neglected in the calculation.

5. Elements

In the early array, with the elements closely spaced, considerable difficulty was encountered in reducing the input impedance of the elements to a satisfactory level over the entire range of scan angles. The element length and tuning stub were readjusted twice a year to obtain this satisfactory level. In addition to this, a section of 75Ω line was needed to reduce the impedance to 50Ω. In the new array, as in the orthogonal, a dipole length was picked experimentally which resulted in an impedance close to 50 ohms over the entire scan angle. The tuning stub and 75Ω cable were eliminated. Figure 10 shows average impedance of a number of elements in a section of the array for a series of scan angles for two-element lengths. The average VSWR is

about 1.35:1, resulting in slightly less loss in the overall system. However, the feed cables from the coupler output to the trough line are longer than in the original array. The shortest length (on every other element) is now $\lambda/2$ or 8-1/2 feet; on the other half of the elements there is at least a 1-1/2 wavelength cable. These elements are in those rows where there is no trough line (Fig. 11). These lengths are in addition to the phasing cable lengths.

6. Ground Plane

The ground plane of the original array was unsatisfactory from a "convenience" point of view. It consisted of galvanized mesh "chicken wire" hexagonal in shape. It became entangled in the lawn mowers and when not re-tacked down would trip people walking in the array. It was decided to bury the ground screen on the new side or in the expanded side of the array. Obviously, the cost of burying "chicken wire" was quite high so a series of aluminum wires were stretched in an east-west direction. These wires were spaced 9 inches apart north-south covered by about 2 to 3 inches of soil. No noticeable difference in electrical effects between the different ground planes has been noticed.

III. DIRECTIVITY AND ESTIMATED GAIN

The formulae for the far-field pattern of the array and of the element as well as the results of these calculations are given in TR-276, Section 2C. The same discussions apply except that the east-west beamwidth of the array is halved. The peak directivity for a uniformly illuminated aperture

is given by $D = 4\pi A/\lambda^2$ where A is the area of array. When the parameters of the new array are used in this equation, the peak directivity of the broadside beam is 38.59 db. Most of the same losses, both radiation and conductor, exist for the new array as for the old. However, there is 1/4 db less loss in the new array resulting from these factors.

(a) The mismatch in the branch lines results in a 0.1 db loss vs. 0.2.

(b) The better arrangement of couplers in the feed lines results in better efficiency of radiated power 84 percent vs. 80 percent. This is an increase of .25 db.

(c) The average phasing and matching cables are longer than they were before resulting in a loss of .25 db vs. .15 db or -0.1 db.

The resultant gain is 36.8 db. In the previous array, the measured gain was 33-1/4 db vs. 33.6 db calculation. No radiation patterns have been measured, or will be measured, with the expanded array. However, the gain of the array has been checked at various scan angles using Virgo, Taurus and Cygnus as sources. In all cases, the gain exceeds 36 db and approaches 37 db.

IV. CONCLUSION

The gain of the El Campo solar radar antenna has been increased by 3 db at a cost of approximately $40,000. Mechanical and electrical improvements have been incorporated to reduce maintenance time and increase reliability.

REFERENCES

1. M. E. Devane and A. R. Dion, "The El Campo Solar Radar Antenna," Technical Report 276, Lincoln Laboratory, M. I. T. (17 August 1962).

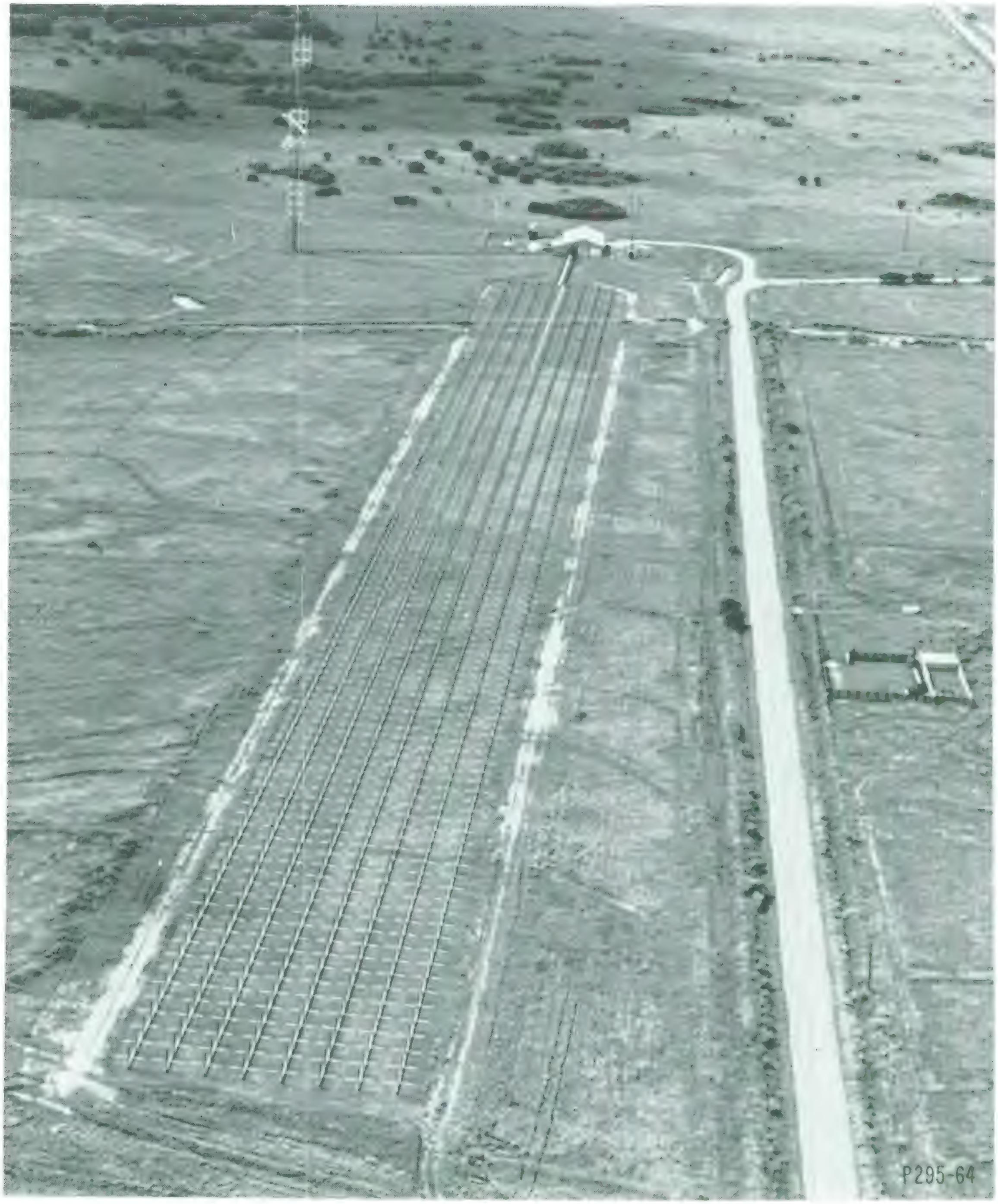

Fig. 1a. Aerial view - original array.

Fig. 1b. Aerial view - expanded array.

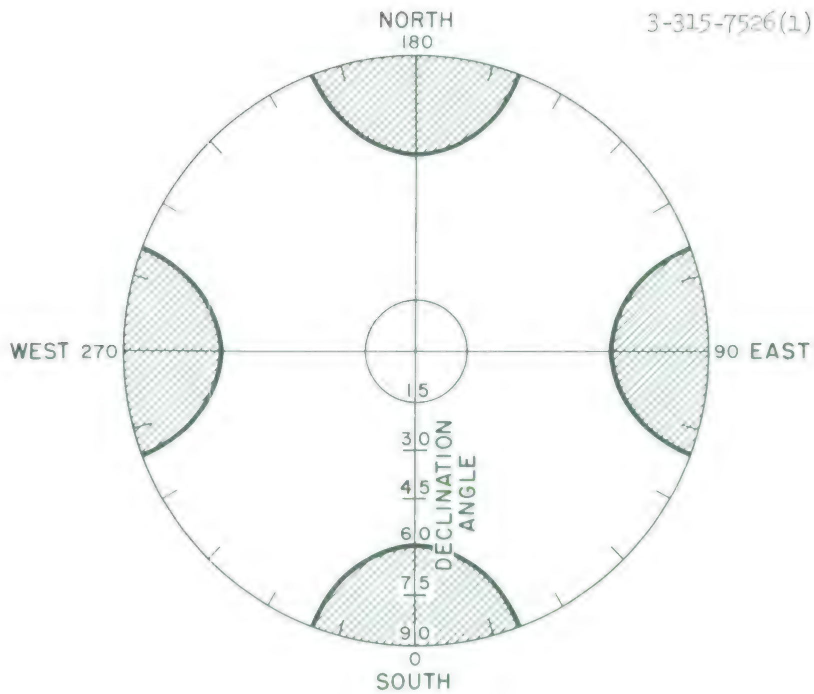

Fig. 2a. Angles over which the beam of the square spaced array may be scanned without formation of grating lobes (outside shaded area).

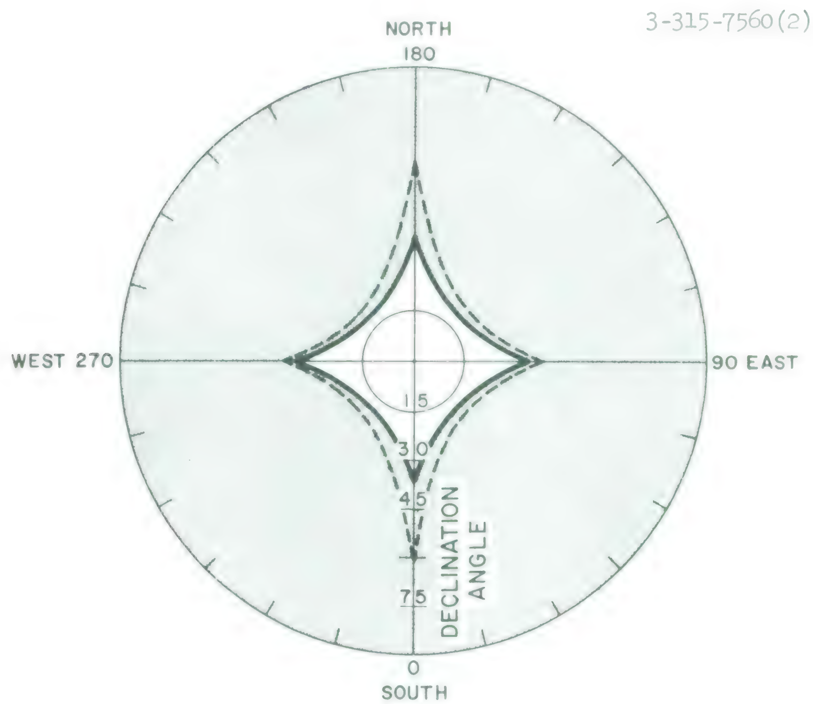

Fig. 2b. Solid angle over which the beam of the triangular lattice array can be scanned without the formation of a grating lobe (outside shaded area). Dashed curve is the locus of beam angles for which a −13 db grating lobe is formed.

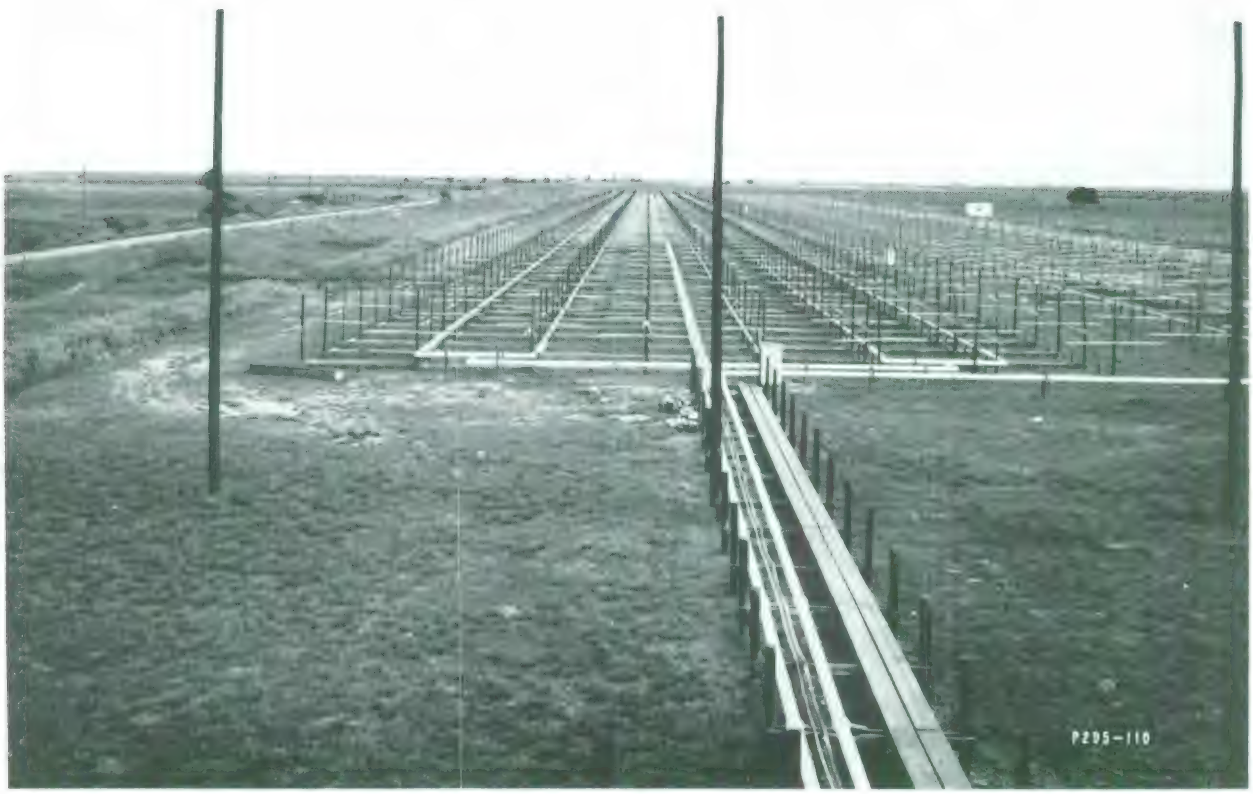

Fig. 3. Feed end of expanded array.

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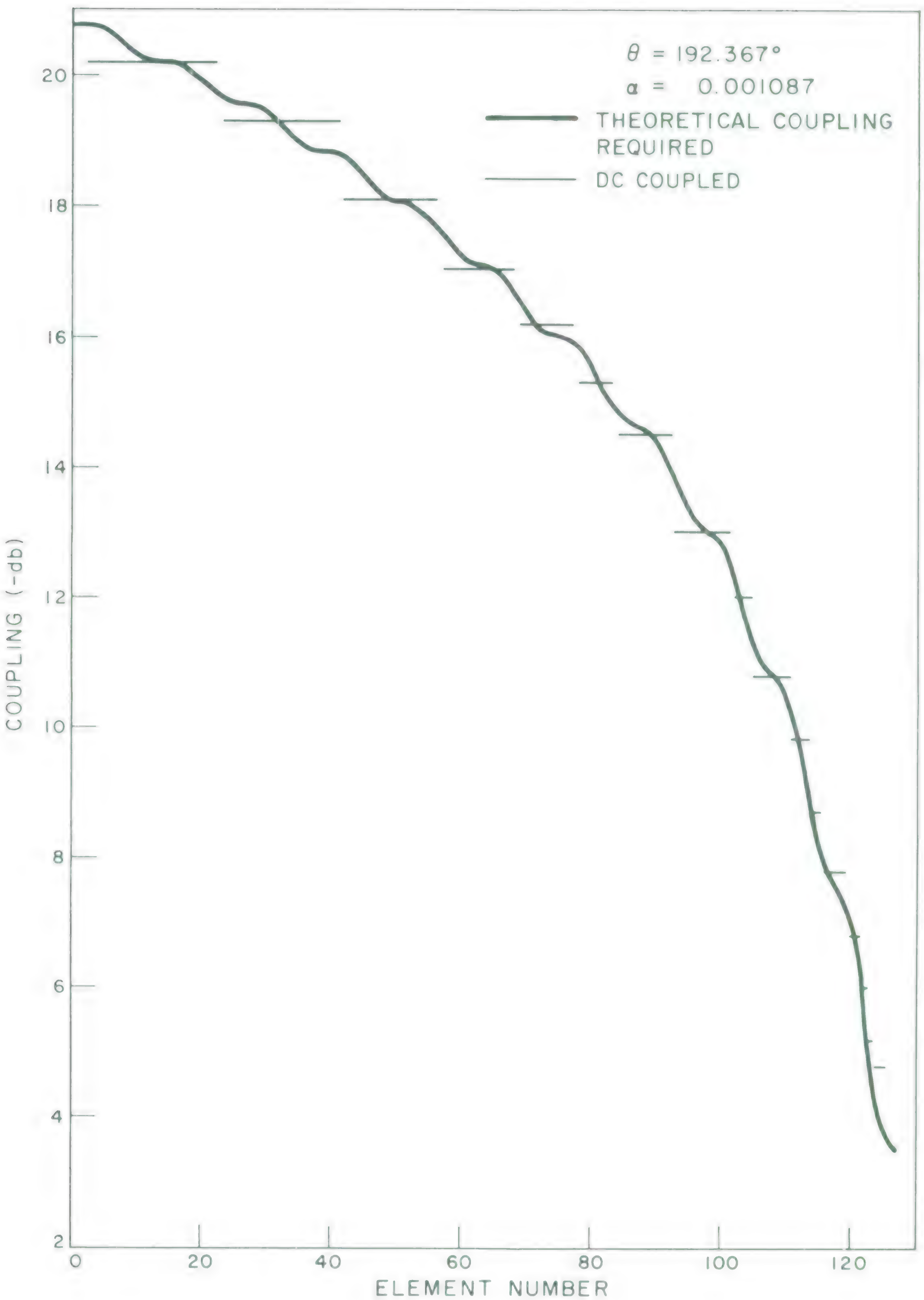

Fig. 4. Theoretical coupling required for uniform illumination and the approximation of this requirement with a minimum number of different couplers.

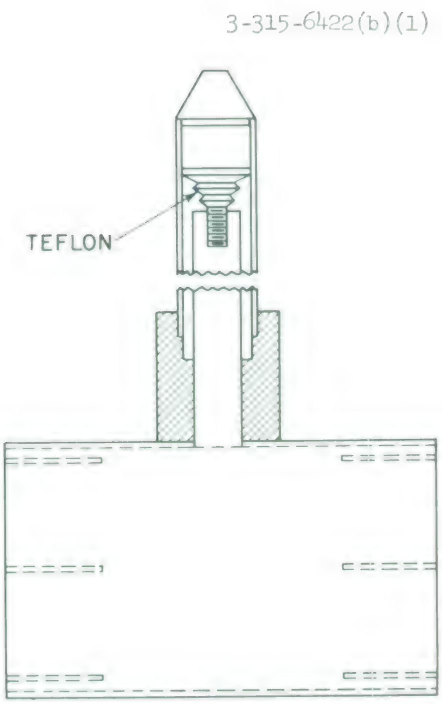

Fig. 5a. A type 1 coupler.

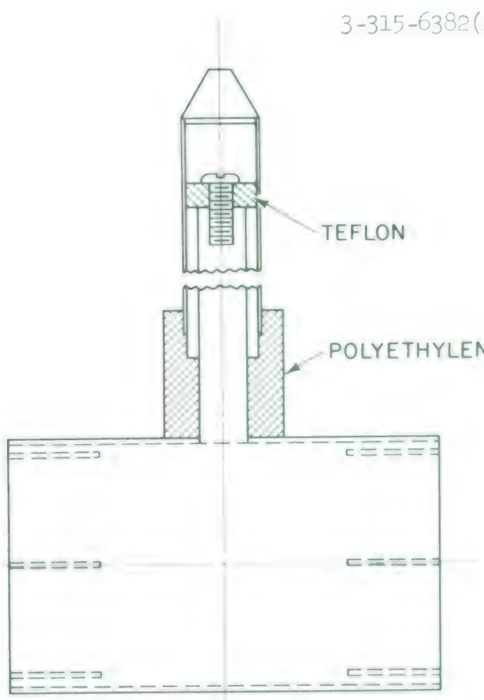

Fig. 5b. Type 2 coupler.

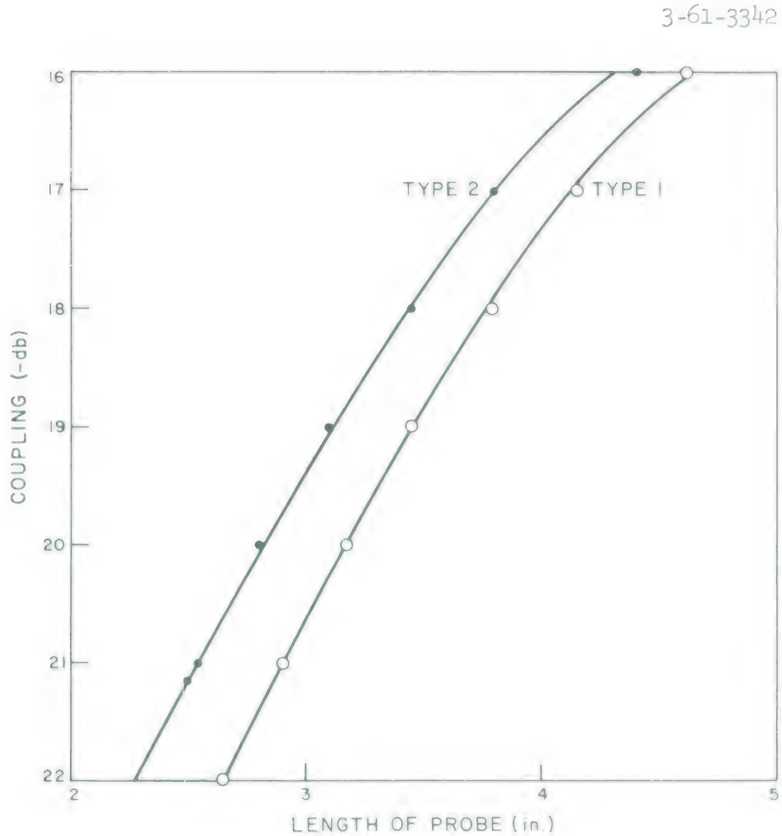

Fig. 6. Probe length vs. coupling.

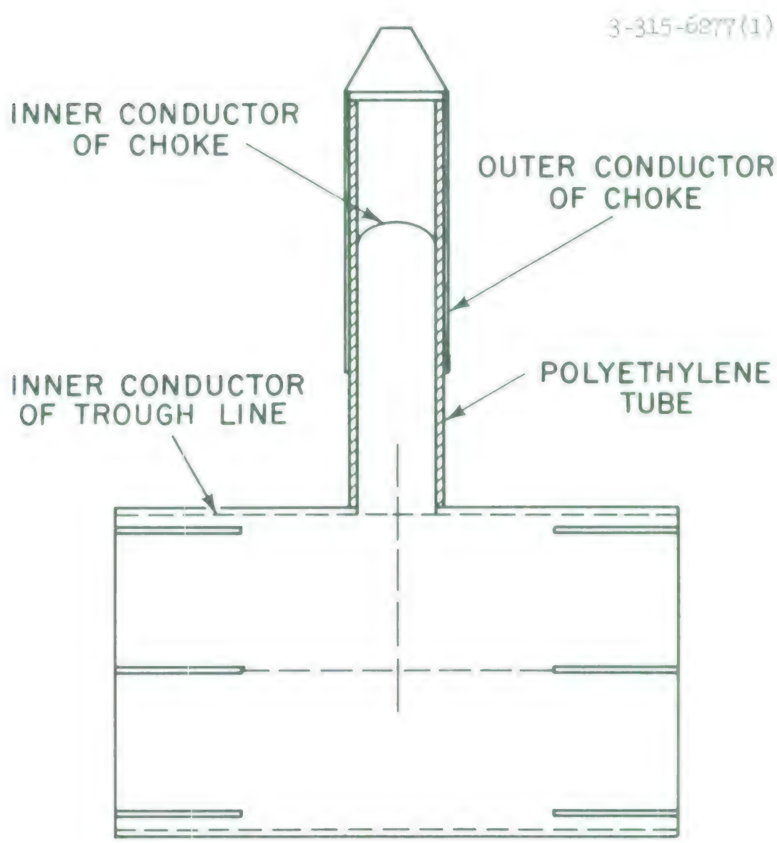

Fig. 7. Original coupler design.

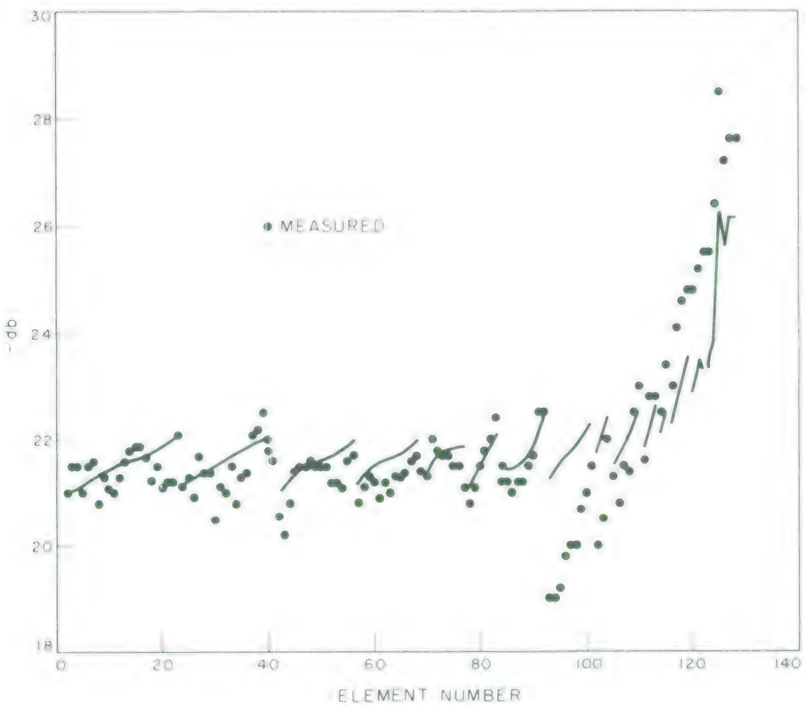

Fig. 8. Theoretical and measured power outputs of a typical row of couplers.

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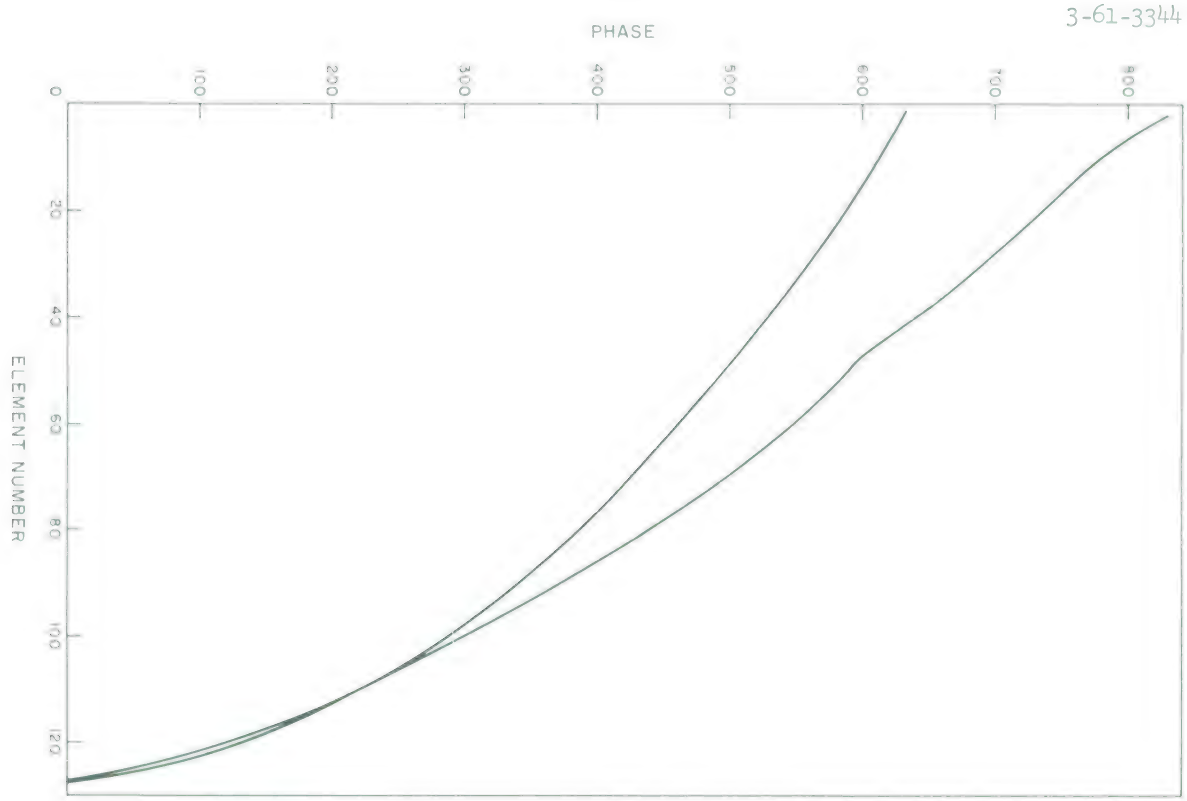

Fig. 9. Theoretical and measured increase in phase due to line loading.

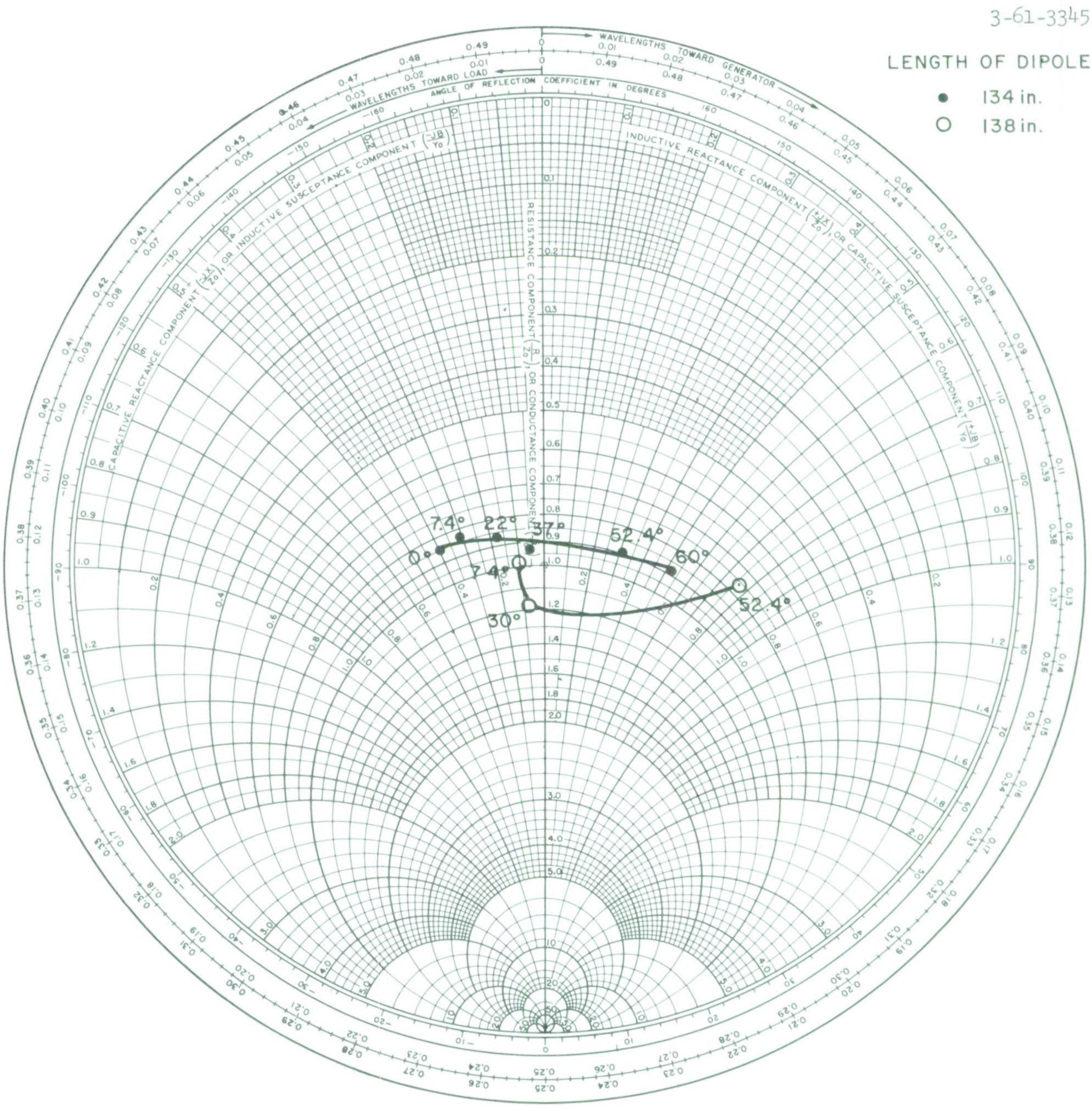

Fig. 10. Average impedance of dipoles for two element lengths.

Fig. 11. Close up of elements and trough line.

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13. ABSTRACT

The east-west aperture of the El Campo Solar Radar Antenna was doubled. Mechanical and electrical improvements incorporated at the time of the expansion, together with the increased size, resulted in an increase in gain of approximately 3-1/4 db.

14. KEY WORDS

El Campo	phase studies	transmission lines
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